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A Method and Device for Multipath Mitigation in Positioning Systems using Clustered Positioning Signals

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The present invention discloses a method and device for the mitigation of code and carrier-phase multipath in positioning systems by means of interpreting unique positioning signals, received through diverse radio frequency (RF) links, which exhibit substantially equal ranges and unit vectors with respect to a roving receiver. The present invention has particular, but not exclusive application in positioning technologies where precise range information free from multipath perturbations is essential for accurate positioning.

Background to the Invention

Multipath is an ever-present problem for all RF communications and RF positioning systems. It causes degraded signal strengths and low data bandwidths for communication systems, and noisy and inaccurate range measurements for positioning systems. In particular, multipath in an indoor environment is very severe, with signals being reflected from most objects including walls, furniture, and people. A number of diversity methods have been developed to mitigate the effects of multipath in communication-based systems. They include spatial, frequency, and polarization diversity. These traditional methods are designed to minimize signal cancellation which is caused by the direct and reflected signals interacting in a destructive manner. These prior art systems choose the antenna element (spatial and polarization diversity) or frequency (frequency diversity) with the highest signal strength, and then use this signal to demodulate data. They do not discriminate in any way between direct and reflected signals. A strong reflected signal with good signal strength will be accepted over a weaker direct signal, with no consideration given to the direction of signal arrival. For positioning systems to function correctly, it is vital that the direct line-of-sight signal is measured. This may not necessarily be the signal with the highest received signal strength. Therefore, traditional prior-art communications-based diversity methods are not suited for the mitigation of multipath in positioning systems.

Traditional multipath mitigation methods for positioning systems fall into three broad categories; multipath limiting antennas, over-determined position solutions, and Receiver Autonomous Integrity Monitoring (RAIM). Multipath limiting antennas shape the receive and/or transmit antenna gain pattern to reduce the strength of reflected, off-axis signals. The most common form

of this antenna is the so-called *choke ring* antenna, generally used in GPS applications for mitigating ground reflections. Mulipath limiting antenna methods orient the beam pattern in one direction and, as such, have limited application in high multipath environments such as indoors, where signals reflect from many directions. Over-determined position solutions use more transmitters than required to form a position solution. This improves position accuracy by decreasing the significance of multipath corrupted positioning signals in the position solution. An added advantage is the improved geometry provided by more geometrically diverse transmitters. However, for this method to be effective, the majority of positioning signals must be non-corrupt at any given time. This is generally not the case in high multipath environments. Receiver Autonomous Integrity Monitoring (RAIM) is an algorithm employed by position receivers to check the integrity of received positioning signals, and hence eliminate outlier measurements from position solutions. In its simplest form a RAIM algorithm uses combinations of transmitter measurements to determine multipath-corrupted outlier ranges, and it then eliminates the transmitters associated with the corrupted ranges from the position solution. Different combinations are achieved by using redundant positioning signal measurements from additional transmitters. Therefore, the RAIM method requires large numbers of transmitters to provide an effective multipath solution, which in many cases is highly impractical. Furthermore, if the RAIM algorithm deems a positioning signal to be multipath corrupted, the transmitter is eliminated from the position solution, which further reduces geometric diversity (i.e. it causes an increase in the Geometric Dilution of Precision).

Therefore, a system which distinguishes between direct and reflected positioning signals without the loss of geometric diversity is highly desirable in positioning systems, especially those required to function indoors.

Disclosure of the Invention

The present invention discloses a method and device for the mitigation of code and carrier-phase multipath in positioning systems by means of interpreting synchronous unique positioning signals, received through diverse radio frequency links, which exhibit substantially equal ranges and unit vectors with respect to a receiving device. A plurality of unique positioning signals which are each synchronously transmitted through a separate diverse radio frequency link, and exhibit substantially equal ranges and unit vectors with respect to a receiving device, are known as a 'transmit cluster'. A transmit cluster is a group of unique positioning signals that are synchronously transmitted from substantially the same geometric location, whilst still retaining radio frequency diversity. A single transmitted positioning signal which is received through a plurality of spatially or polarization diverse antenna elements (diverse receive radio links), and

exhibit substantially equal ranges and unit vectors with respect to a receiving device, is known as a 'receive cluster'. A receive cluster is a group of discrete positioning signals that are synchronously received from substantially the same geometric location, whilst still retaining radio frequency diversity. Radio frequency diversity can be achieved for both transmit and receive clusters using either spatial, frequency, or polarization means. In multipath-free conditions a cluster allows the measurement of coherent positioning signals (pseudoranges, integrated carrier phases, Doppler, and signal strengths) at a roving receiver. This coherence is due to the range and unit vector for each positioning signal being substantially equal with respect to the roving receiver. However, in multipath conditions, a roving receiver will not measure all positioning signals from a cluster coherently. Positioning signal coherence degrades in multipath due to radio frequency link diversity creating disparate multipath reflections, which affect the range measurements of each link individually. In the preferred embodiment a roving receiver is configured to compare a cluster of unique positioning signals and then select substantially coherent positioning signals, such that accurate range measurements can be determined in multipath conditions. Accurate position solutions can therefore be calculated once at least three transmitters are in-view.

Embodiment One – Spatially Diverse Transmit Cluster

A first embodiment of the present invention discloses a method and device for the mitigation of code and carrier-phase multipath in positioning systems by means of transmitting a plurality of synchronous unique positioning signals through a plurality of spatially distributed transmit antenna elements. All transmit antenna elements are positioned with substantially equal ranges and unit vectors with respect to a roving receiver, with each element positioned at a known location and transmitting a unique positioning signal. A roving receiver is configured to receive and interpret the plurality of transmitted unique positioning signals, so as to mitigate the deleterious effect of multipath on positioning accuracy.

Referring now to Fig.1, there is depicted a Positioning-Unit Device **101** transmitting three synchronous unique pseudorandom (PRN) codes **102**, **103**, & **104** via three spatially distributed antenna elements **105**, **106**, & **107**. Each antenna element transmits a unique PRN code. In the preferred embodiment, synchronous unique PRN codes are generated simultaneously from the Positioning-Unit Device and are transmitted simultaneously from each antenna element. In an alternate embodiment, the synchronous unique PRN codes are successively generated within the Positioning-Unit Device and are successively transmitted through each antenna element in a time division multiple access (TDMA) scheme, such that each element transmits a unique PRN code in a unique time slot.

There is no minimum element spacing within a spatially distributed cluster, although the closer the elements are, the greater the multipath coherence between PRN codes becomes, and the less spatial diversity is achieved. The maximum element spacing is dictated by the minimum expected rover separation from the positioning-unit device. For optimum results the unit vector from each antenna element to the roving receiver must be substantially equal. Therefore a roving receiver positioned further away from the positioning-unit device will experience greater similarity of the unit vectors compared to a receiver positioned in close proximity. In the preferred embodiment a cluster of antenna elements is positioned with a half carrier wavelength spacing between elements to maximize the spatial diversity and minimize the unit vector dispersion. At a carrier frequency of 2.4GHz, this represents an antenna element spacing in the order of 60mm.

The first embodiment of the present invention discloses a method and device to mitigate code and carrier phase multipath in roving receiver position solutions by:

A). A Positioning-Unit Device is configured to transmit a plurality of synchronous unique positioning signals from a plurality of spatially distributed antenna elements. The antenna elements are placed with substantially equal ranges and unit vectors with respect to a roving receiver, with each element situated at a known location and transmitting a unique positioning signal. The antenna element spacing is preferably one-half the carrier wavelength, and the synchronous unique positioning signals are CDMA codes (i.e. individual PRN codes) transmitted on identical carrier frequencies.

B) A receiver is configured to receive the plurality of synchronous unique positioning signals transmitted from the plurality of spatially distributed antenna elements and either:

i) Supply all received unique positioning signal pseudorange and/or Integrated Carrier Phase measurements to the receiver positioning algorithm, ready to produce an over-determined position solution once at least three Positioning-Unit Devices are in-view, or

ii) Combine and average all received unique positioning signal pseudorange and/or Integrated Carrier Phase measurements to form a single pseudorange and/or single Integrated Carrier Phase measurement, ready to produce a standard position solution once at least three Positioning-Unit Devices are in-view, or

iii) Determine the coherence between all received unique positioning signals by comparing information selected from the group comprising of pseudoranges, Integrated Carrier Phase measurements, Doppler measurements, and received signal strengths, to:

a) select substantially coherent signals for supply to the positioning algorithm, ready to produce an over-determined position solution once at least three Positioning-Unit Devices are in-view, or

b) select substantially coherent signals for combining and averaging of positioning signals to form a single pseudorange and/or a single Integrated Carrier Phase measurement, ready to produce a standard position solution once at least three Positioning-Unit Devices are in-view, or

c) select substantially coherent signals and estimate a single pseudorange and/or a single Integrated Carrier Phase measurement using a "best fit" algorithm, such as a least squares regression, or any other suitable estimator algorithm. A standard position solution is computed once at least three Positioning-Unit Devices are in view.

Embodiment Two – Frequency Diverse Transmit Cluster

A second embodiment of the present invention discloses a method and device to mitigate code and carrier phase multipath in roving receiver position solutions by:

A) A Positioning-Unit Device is configured to transmit a plurality of synchronous unique positioning signals on a plurality of frequencies, with each unique positioning signal being transmitted on its own unique frequency. The plurality of positioning signals are transmitted through a single antenna element placed at a known location. Preferably the unique positioning signals are CDMA codes (i.e. individual PRN codes) transmitted on individual carrier frequencies.

B) A receiver is configured to receive the plurality of unique positioning signals transmitted on the plurality of frequencies and either:

i) Supply all received unique positioning signal pseudorange and/or Integrated Carrier Phase measurements to the receiver positioning algorithm, ready to produce an over-determined position solution once at least three Positioning-Unit Devices are in-view, or

ii) Combine and average all received unique positioning signal pseudorange and/or Integrated Carrier Phase measurements to form a single pseudorange and/or single Integrated Carrier Phase measurement, ready to produce a standard position solution once at least three Positioning-Unit Devices are in-view, or

iii) Determine the coherence between all received unique positioning signals by comparing information selected from the group comprising of pseudoranges, Integrated Carrier Phase measurements, Doppler measurements, and received signal strengths, to:

a) select substantially coherent signals for supply to the positioning algorithm, ready to produce an over-determined position solution once at least three Positioning-Unit Devices are in-view, or
b) select substantially coherent signals for combining and averaging of positioning signals to form a single pseudorange and/or a single Integrated Carrier Phase measurement, ready to produce a standard position solution once at least three Positioning-Unit Devices are in-view, or
c) select substantially coherent signals and estimate a single pseudorange and/or a single Integrated Carrier Phase measurement using a "best fit" algorithm, such as a least squares regression, or any other suitable estimator algorithm. A standard position solution is computed once at least three Positioning-Unit Devices are in view.

Embodiment Three – Polarization Diverse Transmit Cluster

A third embodiment of the present invention discloses a method and device to mitigate code and carrier phase multipath in roving receiver position solutions by:

A) A Positioning-Unit Device is configured to transmit a plurality of synchronous unique positioning signals from a plurality of orthogonally polarized antenna elements. The antenna elements are placed with substantially equal range and unit vectors with respect to all roving receivers, with each element situated at a known location and transmitting a unique positioning signal. Preferably the antenna elements are placed closely together, and the unique positioning signals are CDMA codes (i.e. individual PRN codes) transmitted on identical carrier frequencies.

B) A receiver is configured to receive the plurality of unique positioning signals transmitted from the plurality of orthogonally polarized antenna elements and either:

i) Supply all received unique positioning signal pseudorange and/or Integrated Carrier Phase measurements to the receiver positioning algorithm, ready to produce an over-determined position solution once at least three Positioning-Unit Devices are in-view, or

ii) Combine and average all received unique positioning signal pseudorange and/or Integrated Carrier Phase measurements to form a single pseudorange and/or single Integrated Carrier Phase measurement, ready to produce a standard position solution once at least three Positioning-Unit Devices are in-view, or

iii) Determine the coherence between all received unique positioning signals by comparing information selected from the group comprising of pseudoranges, Integrated Carrier Phase measurements, Doppler measurements, and received signal strengths, to:

a) select substantially coherent signals for supply to the positioning algorithm, ready to produce an over-determined position solution once at least three Positioning-Unit Devices are in-view, or

b) select substantially coherent signals for combining and averaging of positioning signals to form a single pseudorange and/or a single Integrated Carrier Phase measurement, ready to produce a standard position solution once at least three Positioning-Unit Devices are in-view, or

c) select substantially coherent signals and estimate a single pseudorange and/or a single Integrated Carrier Phase measurement using a "best fit" algorithm, such as a least squares regression, or any other suitable estimator algorithm. A standard position solution is computed once at least three Positioning-Unit Devices are in view.

Embodiment Four – Spatially Diverse Receive Cluster

The present invention also discloses a method and device for the mitigation of code and carrier-phase multipath in positioning systems by means of receiving a unique positioning signal through a plurality of spatially distributed receive antenna elements. All receive antenna elements are positioned with substantially equal unit vectors with respect to the transmitted signal (preferably all receive antenna elements are positioned one-half carrier wavelength, or less, apart), with each element positioned in a known relation to one another and individually receiving the same unique positioning signal. The receiver is configured to individually receive, track, and interpret the plurality of discrete positioning signals, so as to mitigate the deleterious effect of multipath on positioning accuracy.

The fourth embodiment of the present invention discloses a method and device to mitigate code and carrier phase multipath in roving receiver position solutions by:

A) A Positioning-Unit Device is configured to transmit a single positioning signal from a single antenna. The antenna is situated at a known location and transmitting a unique positioning signal.

B) A receiver is configured to receive the unique positioning signal through a plurality of spatially distributed antenna elements. Each antenna element is connected to a discrete receiver path, with each receiver path being synchronized from a common clock. (Alternatively, each antenna element is successively switched to different receive channels within a single receiver path.) The plurality of discrete receiver paths creates a plurality of discrete pseudorange, Integrated Carrier Phase, Doppler, and signal strength measurements from the single transmitted positioning signal. The receiver is configured to receive the plurality of discrete positioning signals through the plurality of spatially distributed antenna elements and either:

i) Supply all received discrete positioning signal pseudorange and/or Integrated Carrier Phase measurements to the receiver positioning algorithm, ready to produce an over-determined position solution once at least three Positioning-Unit Devices are in-view, or

ii) Combine and average all received discrete positioning signal pseudorange and/or Integrated Carrier Phase measurements to form a single pseudorange and/or single Integrated Carrier Phase measurement, ready to produce a standard position solution once at least three Positioning-Unit Devices are in-view, or

iii) Determine the coherence between all received discrete positioning signals by comparing information selected from the group comprising of pseudoranges, Integrated Carrier Phase measurements, Doppler measurements, and received signal strengths, to:

a) select substantially coherent signals for supply to the positioning algorithm, ready to produce an over-determined position solution once at least three Positioning-Unit Devices are in-view, or
b) select substantially coherent signals for combining of positioning signals to form a single pseudorange and/or a single Integrated Carrier Phase measurement, ready to produce a standard position solution once at least three Positioning-Unit Devices are in-view, or
c) select substantially coherent signals and estimate a single pseudorange and/or a single Integrated Carrier Phase measurement using a "best fit" algorithm, such as a least squares regression, or any other suitable estimator algorithm. A standard position solution is computed once at least three Positioning-Unit Devices are in view.

Embodiment Five – Polarization Diverse Receive Cluster

The present invention discloses a method and device for the mitigation of code and carrier-phase multipath in positioning systems by means of receiving a unique positioning signal through a

plurality of polarization diverse receive antenna elements. All receive antenna elements are positioned with substantially equal range and unit vectors with respect to the transmitted signal (i.e. positioned as close as practicable), with each element positioned in a known relation to one another and individually receiving the same unique positioning signal. The receiver is configured to individually receive, track, and interpret the plurality of discrete positioning signals, so as to mitigate the deleterious effect of multipath on positioning accuracy.

The fifth embodiment of the present invention discloses a method and device to mitigate code and carrier phase multipath in roving receiver position solutions by:

A) A Positioning-Unit Device is configured to transmit a single positioning signal from a single antenna. The antenna is situated at a known location and transmitting a unique positioning signal.

B) A receiver is configured to receive the unique positioning signal through a plurality of orthogonally polarized antenna elements. Each antenna element is connected to a discrete receiver path, with each receiver path being synchronized from a common clock. (Alternatively, each antenna element is successively switched to different receive channels within a single receiver path.) The plurality of discrete receiver paths create a plurality of discrete pseudorange, Integrated Carrier Phase, Doppler, and signal strength measurements from a single transmitted positioning signal. The receiver is configured to receive the plurality of discrete positioning signals through the plurality of orthogonally polarized antenna elements and either:

   i) Supply all received discrete positioning signal pseudorange and/or Integrated Carrier Phase measurements to the receiver positioning algorithm, ready to produce an over-determined position solution once at least three Positioning-Unit Devices are in-view, or

   ii) Combine and average all received discrete positioning signal pseudorange and/or Integrated Carrier Phase measurements to form a single pseudorange and/or single Integrated Carrier Phase measurement, ready to produce a standard position solution once at least three Positioning-Unit Devices are in-view, or

iii) Determine the coherence between all received discrete positioning signals by comparing information selected from the group comprising of pseudoranges, Integrated Carrier Phase measurements, Doppler measurements, and received signal strengths, to:

a) select substantially coherent signals for supply to the positioning algorithm, ready to produce an over-determined position solution once at least three Positioning-Unit Devices are in-view, or

b) select substantially coherent signals for combining of positioning signals to form a single pseudorange and/or a single Integrated Carrier Phase measurement, ready to produce a standard position solution once at least three Positioning-Unit Devices are in-view, or

c) select substantially coherent signals and estimate a single pseudorange and/or a single Integrated Carrier Phase measurement using a "best fit" algorithm, such as a least squares regression, or any other suitable estimator algorithm. A standard position solution is computed once at least three Positioning-Unit Devices are in view.

Receiver Interpretation

A receiver is configured to receive and interpret a plurality of unique and/or discrete positioning signals (preferably CDMA pseudorandom codes) received from positioning signal clusters. The receiver assigns a number of receive channels equal to the number of positioning signals to be tracked. It then autonomously tracks information selected from the group comprising of unique PRN code pseudorange, discrete PRN code pseudorange, Integrated Carrier Phase, Doppler measurement and signal strength measurement, received from each radio frequency link. This autonomous tracking of selected PRN code pseudoranges allows independent measurement of all positioning signals from a cluster, without any measurement being corrupted by another. The receiver subsequently processes the received measurements in one of the following manners:

Receiver Embodiment One

In a first receiver embodiment of the present invention, the roving receiver supplies received information selected from the group comprising of unique PRN code pseudorange, discrete PRN code pseudorange and Integrated Carrier Phase, to the receiver positioning algorithm. The

receiver positioning algorithm subsequently uses all available positioning signals to produce an over-determined position solution once at least three Positioning-Unit Devices are in-view.

Receiver Embodiment Two

In a second receiver embodiment of the present invention, the roving receiver calculates the mean of all information, selected from the group comprising of unique PRN code pseudorange, discrete PRN code pseudorange and Integrated Carrier Phase, which is received from a cluster and forms a low noise single pseudorange and/or a low noise single Integrated Carrier Phase measurement. The low noise pseudorange and Integrated Carrier Phase measurements are subsequently passed to the position algorithm, ready to determine a position solution once at least three Positioning-Unit Devices are in-view.

Receiver Embodiment Three

In a third receiver embodiment of the present invention, a preprocess algorithm within the position receiver determines coherence of range measurements received from a cluster, and passes substantially coherent range measurements to the receiver positioning algorithm. Substantially coherent positioning signals are signals that produce similar pseudorange, integrated carrier phase, Doppler, and signal strength measurements in a position receiver within predetermined tolerance values. For example, tolerance values may be configured such that measured pseudoranges within 5 metres of one another are deemed code-coherent, Integrated Carrier Phase measurements that are within 0.25 cycles of one another are deemed carrier-coherent, carrier DCO values that are within 0.1 Hertz of one another are deemed Doppler-coherent, and received signal strengths that are within 2dB of one another are deemed signal strength-coherent.

A comparison of PRN codes is undertaken by the preprocess algorithm to determine coherency between pseudoranges, Integrated Carrier Phase measurements, Doppler measurements (i.e. carrier DCOs), and signal strength measurements. Signals deemed substantially coherent are passed to the positioning algorithm. Signals deemed non-coherent are assumed to be affected by multipath and are eliminated from the range measurement. The receiver positioning algorithm subsequently uses all substantially coherent positioning signals from at least three Positioning-Unit Devices in-view to produce an over-determined position solution.

Receiver Embodiment Four

In a fourth receiver embodiment of the present invention a preprocess algorithm within the position receiver determines coherence of range measurements received from a cluster, and

calculates the mean of all substantially coherent range measurements before passing a low noise single range measurement to the position algorithm. A comparison of PRN codes is undertaken by the preprocess algorithm to determine coherency between pseudoranges, Integrated Carrier Phase measurements, Doppler measurements, and signal strength measurements. Signals deemed substantially coherent are combined to form a single low noise range measurement. Signals deemed non-coherent are assumed to be affected by multipath and are eliminated from the range measurement. A low noise pseudorange and/or Integrated Carrier Phase measurement is subsequently passed to the position algorithm, ready to determine a position solution once at least three Positioning-Unit Devices are in-view.

Receiver Embodiment Five

In a fifth receiver embodiment of the present invention, a preprocess algorithm within the position receiver determines coherence of range measurements received from a cluster, and subsequently estimates the "best fit" range measurement from substantially coherent positioning signals before passing a single pseudorange and/or Integrated Carrier Phase measurement to the position algorithm. A comparison of PRN codes is undertaken by the preprocess algorithm to determine coherency between pseudoranges, Integrated Carrier Phase measurements, Doppler measurements, and signal strength measurements. All substantially coherent measurements are passed to an estimator algorithm to determine a "best fit" range measurement. The estimator may include any appropriate mathematical algorithm which produces a "best fit" solution, such as, for example, a least squares regression. The "best fit" pseudorange and/or Integrated Carrier Phase measurement is subsequently passed to the position algorithm, ready to determine a position solution once at least three Positioning-Unit Devices are in-view.

Receiver Embodiment Six

In a sixth receiver embodiment of the present invention, a preprocess algorithm within the position receiver estimates the "best fit" range measurement received from a cluster, before passing a single pseudorange and/or Integrated Carrier Phase measurement to the position algorithm. All pseudoranges, Integrated Carrier Phase measurements, Doppler measurements, and signal strength measurements from a cluster are passed to an estimator algorithm to determine a "best fit" range measurement. The estimator may include any appropriate mathematical algorithm which produces a "best fit" solution, such as, for example, a least squares regression. The "best fit" pseudorange and/or Integrated Carrier Phase measurement is subsequently passed to the position algorithm, ready to determine a position solution once at least three Positioning-Unit Devices are in-view.

Receiver Embodiment Seven

In a seventh receiver embodiment of the present invention, the roving receiver supplies all received positioning signals (preferably pseudoranges, Integrated Carrier Phase measurements, Doppler measurements, and signal strength measurements) to the receiver positioning algorithm, which employs a specific and optimized RAIM (Receiver Autonomous Integrity Monitoring) algorithm. With at least three Positioning-Unit Devices in-view the RAIM algorithm selects the best positioning signals from each Positioning-Unit Device and subsequently uses these "best fit" signals in the position solution.

Receiver Embodiment eight

In an eighth receiver embodiment of the present invention, the roving receiver supplies all received positioning signals (preferably pseudoranges, Integrated Carrier Phase measurements, Doppler measurements, and signal strength measurements) from all positioning-unit devices in-view to an estimator. The estimator may include any appropriate mathematical algorithm which produces a "best fit" solution, for example a Kalman Filter. The estimator estimates the best range measurement from each positioning-unit device using all pseudorange, Integrated Carrier Phase, Doppler, and signal strength measurements once at least three Positioning-Unit Devices are in-view.

Carrier DCO

Within the scope of the present invention, particular attention is given to the carrier digital controlled oscillator (DCO) value of each tracking channel. The carrier DCO tracks and measures the velocity of the roving receiver relative to the transmitter (known as Doppler) and it also measures receiver clock drift. All Doppler measurements from a cluster will be identical in a multipath-free environment, irrespective of the common-mode receiver clock drift. In multipath environments the carrier DCOs (i.e the carrier tracking loops) are easily destabilized due to the large fluctuations in phase and signal power caused by reflected signals combining in constructive and destructive manners. Armed with the knowledge that all DCO values from a cluster will be substantially equal in a multipath-free environment, it is possible to accurately estimate the correct DCO value in multipath conditions by comparing all DCO values from a cluster and determining a "best fit" DCO value, each measurement epoch. This best fit DCO value is subsequently used to generate the Integrated Carrier Phase measurement, which is used to determine an accurate change-in-range measurement.

Pseudorange Noise

Pseudorange measurements are inherently noisy and affected heavily by multipath. Traditional methods involve increasing the chipping rate of the pseudorandom code to decrease pseudorange noise, and hence improve multipath mitigation. Increased chipping rates increase RF bandwidth, receiver power consumption and receiver complexity. The present invention discloses a method whereby a plurality of diverse unique positioning signals, with substantially equal unit vectors and ranges, are combined and averaged in parallel to decrease pseudorange noise and mitigate multipath, without the constraints imposed by faster chipping rates.

Diversity

Diverse RF links can be created at either the transmitter or receiver, or at both the transmitter and the receiver simultaneously. Preferably RF link diversity is achieved using either spatial, frequency, or polarization means.

Transmit Diversity

Transmit diversity is preferably achieved using spatial, frequency, or polarization means, although other forms of diversity could be used and remain within the broad ambit of the invention. Transmit spatial diversity requires a plurality of antenna elements to be placed closely together (preferably one-half carrier wavelength), with each element situated at a known location and transmitting a unique synchronous positioning signal. Transmit frequency diversity requires the transmission of a plurality of frequencies through an antenna element placed at a known location, with each frequency transmitting a unique synchronous positioning signal. Transmit polarization diversity requires a plurality of uniquely polarized antenna elements to be placed closely together (preferably less than one-half of the carrier cycle Dave.. should this be "carrier wavelength"??), with each element situated at a known location and transmitting a unique synchronous positioning signal. Combinations of spatial, frequency, and polarization diversity may be introduced to generate even greater diversity. For example, a cluster of spatially distributed antenna elements with unique polarization characteristics may each transmit a plurality of unique positioning signals on a plurality of frequencies.

Receive Diversity

Receive diversity is also preferably achieved using spatial, frequency, or polarization means, although other forms of diversity could be used and remain within the broad ambit of the invention. Receive spatial diversity requires a plurality of antenna elements to be placed closely together (preferably one-half of the carrier wavelength), with each element individually receiving and tracking the same transmitted unique positioning signal. Receive frequency diversity requires

the individual reception of a plurality of unique synchronous positioning signals which have been transmitted on a plurality of frequencies. Receive polarization diversity requires a plurality of uniquely polarized antenna elements to be placed closely together (preferably less than one-half the carrier wavelength), with each element individually receiving and tracking the same unique positioning signal. Combinations of receive spatial, frequency, and polarization diversity may be introduced to generate even greater diversity. For example, a cluster of spatially distributed antenna elements with unique polarization characteristics may each receive a plurality of unique positioning signals on a plurality of frequencies.

Transmitted Spatial Diversity

Unique synchronous positioning signals transmitted in a multipath-free environment from closely spaced antenna elements (preferably spaced at one-half of the carrier wavelength) exhibit substantially coherent pseudorange, Integrated Carrier Phase, Doppler, and signal strength measurements at a roving receiver. This coherence is due to the unit vector and distance from each antenna element to the roving receiver being substantially equal. However, in a multipath environment the unique synchronous positioning signals transmitted from closely spaced antenna elements do not all exhibit coherent pseudorange, Integrated Carrier Phase, Doppler, and signal strength measurements at the roving receiver. This non-coherence is due to the roving receiver measuring different reflected path signals (multipath) from each antenna element which, when combined with their respective direct signals, cause different range and signal strength measurements for each positioning signal. The amount of non-coherence between positioning signals depends upon the severity of the multipath environment.

Receive Spatial Diversity

A unique positioning signal received at a roving receiver through closely spaced receive antenna elements (preferably spaced at one-half of the carrier wavelength), which are individually interpreted through separate receive channels, creates a plurality of discrete positioning signals from the one transmitted positioning signal. These discrete positioning signals exhibit substantially coherent pseudorange, Integrated Carrier Phase, Doppler, and signal strength measurements in a multipath-free environment due to the unit vector and distance from each receive antenna element to the transmitter being substantially equal. However, in a multipath environment the discrete positioning signals received from closely spaced receive antenna elements exhibit non-coherent pseudorange, Integrated Carrier Phase and signal strength measurements at the roving receiver. This non-coherence is due to the roving receiver measuring different reflected path signals (multipath) from each receive antenna element which, when

combined with their respective direct signals, cause different range and signal strength measurements for each positioning signal. The amount of non-coherence between positioning signals depends upon the severity of the multipath environment.

Transmit & Receive Spatial Diversity

Unique synchronous positioning signals transmitted in a multipath-free environment from closely spaced antenna elements (preferably spaced at one-half of the carrier wavelength), and received at a roving receiver through closely spaced receive antenna elements (preferably spaced at one-half of the carrier wavelength) which are individually interpreted through separate receive channels, creates a plurality of unique and discrete positioning signals which exhibit substantially coherent pseudorange, Integrated Carrier Phase (ICP), Doppler, and signal strength measurements. This coherence is due to the unit vector and distance between transmit and receive antenna elements being substantially equal. However, in a multipath environment the unique and discrete positioning signals exhibit non-coherent pseudorange, Integrated Carrier Phase and signal strength measurements at the roving receiver. This non-coherence is due to the roving receiver measuring different reflected path signals (multipath) for each receive and transmit antenna element which, when combined with their respective direct signals, cause different range and signal strength measurements for each positioning signal. The amount of non-coherence between positioning signals depends upon the severity of the multipath environment.

Further Diversity Embodiments The present invention may further embody any combination of the above described diverse RF link methods for increased diversity. For example, the present invention discloses a method and device for the mitigation of code and carrier-phase multipath in positioning systems by means of a positioning-unit device transmitting a plurality of synchronous unique positioning signals through a plurality of spatially distributed transmit antenna elements. All transmit antenna elements are positioned with substantially equal unit vectors with respect to a roving receiver, with each element positioned at a known location and transmitting a unique positioning signal. The roving receiver receives the plurality of transmitted unique positioning signals through a plurality of spatially distributed receive antenna elements. All receive antenna elements are positioned with substantially equal unit vectors with respect to the transmitted unique positioning signal, with each element positioned in a known relation to one another and receiving the same unique positioning signals. The roving receiver is configured to receive and interpret the plurality of unique positioning signals transmitted from the plurality of spatially distributed transmit antenna elements, and is also configured to receive and interpret the plurality of discrete positioning signals received from the plurality of spatially distributed receive antenna elements, so as to mitigate the deleterious effect of multipath on positioning accuracy.

Single Frequency Diversity Combinations

With single frequency diversity combinations, the roving receiver receives and interprets a plurality of unique positioning signals transmitted from a transmitter cluster, and also receives and interprets a plurality of discrete positioning signals received from its own receiver cluster. Single frequency diversity combinations include:

- A spatially diverse transmitter cluster transmitting a plurality of unique positioning signals to a spatially diverse receiver cluster.
- A spatially diverse transmitter cluster transmitting a plurality of unique positioning signals to a polarization diverse receiver cluster.
- A polarization diverse transmitter cluster transmitting a plurality of unique positioning signals to a polarization diverse receiver cluster.
- A polarization diverse transmitter cluster transmitting a plurality of unique positioning signals to a spatially diverse receiver cluster.

Furthermore, the present invention allows for any combination of transmit diversity methods, which may include:

A spatially diverse transmitter cluster combined with a frequency diverse transmitter cluster transmitting a plurality of unique positioning signals to a multi-frequency receiver.

A polarization diverse transmitter cluster combined with a frequency diverse transmitter cluster transmitting a plurality of unique positioning signals to a multi-frequency receiver.

A spatially diverse transmitter cluster combined with a polarization diverse transmitter cluster transmitting a plurality of unique positioning signals to a single frequency receiver.

A spatially diverse transmitter cluster combined with a frequency diverse transmitter cluster combined with a polarization diverse transmitter cluster transmitting a plurality of unique positioning signals to a multi-frequency receiver.

Multipath Severity Indicator

The level of non-coherence of positioning signals measured from a cluster can also be used as a multipath severity indicator (MSI). Low levels of coherence indicates heavy multipath, and high levels of coherence indicate low multipath. A roving receiver can use the MSI to determine multipath severity from each positioning-unit device before selecting the best set of positioning-unit devices (i.e the Positioning-Unit Devices least affected by multipath) to provide to the position algorithm.

Cycle Slip Detection & Repair

Non-coherence of positioning signals from a cluster also provides a robust carrier cycle slip detection method. Cycle slips are detected by comparing positioning signals from a cluster and identifying half or whole cycle step functions in the Integrated Carrier Phase measurements, and/or identifying 'spikes' in the carrier DCO values, and/or identifying 'spikes' in the pseudorange measurements, and/or identifying abrupt signal strength fades. When a cycle slip is detected it is a simple matter of correcting the Integrated Carrier Phase measurement of the offending channel the requisite number of half cycles to bring it back into agreement with the Integrated Carrier Phase measurements of the other positioning signals within the cluster.

It will of course be realized that whilst the above has been given by way of an illustrative example of this invention, all such and other modifications and variations hereto, as would be apparent to persons skilled in the art, are deemed to fall within the broad scope and ambit of this invention as is herein set forth.

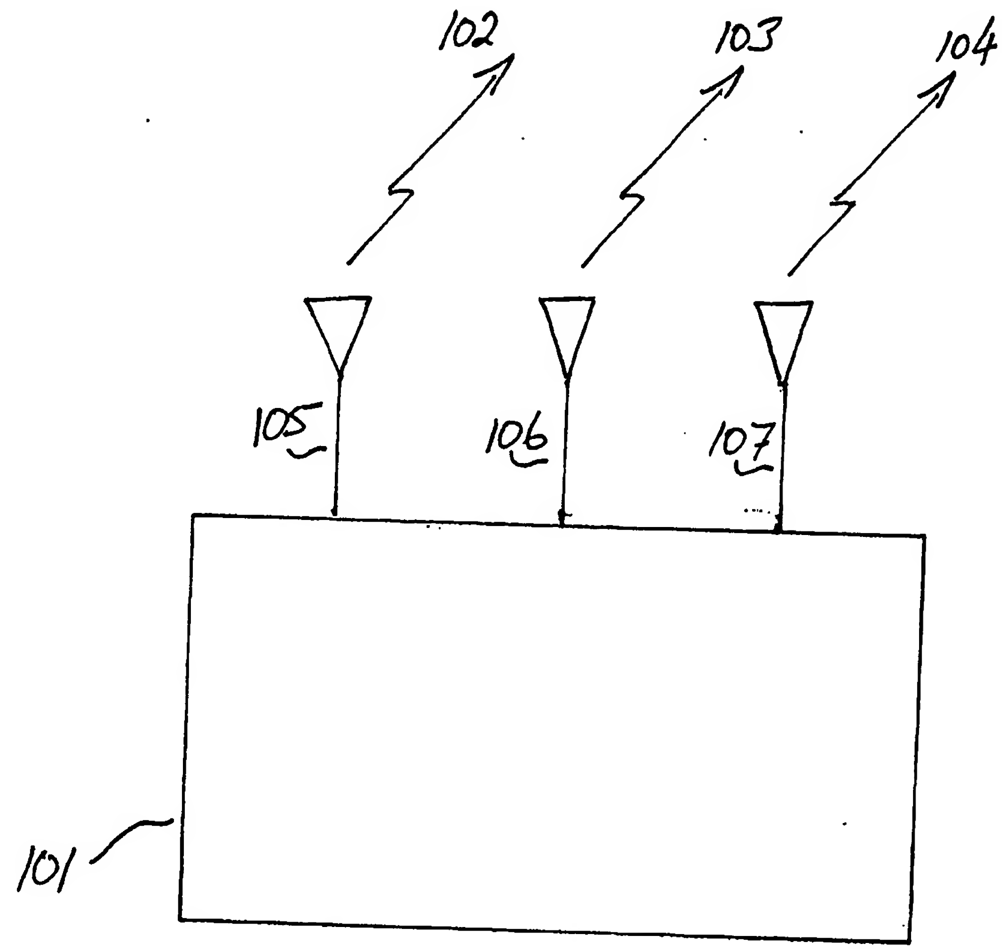

FIG. 1